PHYSICAL CHARACTERIZATION OF ELECTRONIC MATERIALS, DEVICES AND THIN FILMS

S. Andrew Kulin, et al

ManLabs, Incorporated

Prepared for:

Air Force Cambridge Research Laboratories

1 December 1972

AFCRL-TR-73-0070

PHYSICAL CHARACTERIZATION OF ELECTRONIC MATERIALS, DEVICES AND THIN FILMS

by

S. Andrew Kulin

Konstantin Kreder

ManLabs, Inc.
21 Erie Street
Cambridge, Massachusetts 02139

CONTRACT NO. F19628-70-C-0140

Project No. 5620
Task No. 562003
Work Unit No. 56200301

Final Report

1 December 1969 — 30 November 1972

1 December 1972

Contract Monitor: Norman E. Pickering
Solid State Sciences Laboratory

Prepared for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS 01730

27

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
ManLabs, Inc. 21 Erie Street Cambridge, Massachusetts 02139	UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE
PHYSICAL CHARACTERIZATION OF ELECTRONIC MATERIALS, DEVICES AND THIN FILMS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Scientific. Final. 1 December 1969 - 30 November 1972. Approved 1 March 1973

5. AUTHOR(S) (First name, middle initial, last name)
S. Andrew Kulin
Konstantin Kreder

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1, 1972	25	0

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
F19628-70-C-0140 b. PROJECT NO., Task, Work Unit Nos. 5620-03-01 c. DoD Element 61102F d. DoD Subelement 681301	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFCRL-TR-73-0070

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
TECH, OTHER	Air Force Cambridge Research Laboratories (LQ) L. G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

In support of research being conducted by the Properties and Phenomena Branch, Solid State Sciences Laboratory, Air Force Cambridge Research Laboratories, ManLabs, Inc. is conducting a service effort that is directed toward the characterization of specified physical, chemical and structural properties of various materials. Experimental methods include chemical analysis, electron microscopy and reflection diffraction, X-ray diffraction and fluorescence analysis, light microscopy and electron microprobe analysis, in addition to the determination of specific properties, such as density, hardness and thermal conductivity. Special services, such as crystal orientation, cutting, grinding and polishing are also being performed. Specific materials submitted for characterization include lithium germanate, silicon, silicon carbide, quartz, ruby, gallium arsenide, boron, lithium niobate, lithium tantalate, lithium fluoride, potassium chloride, sodium chloride, potassium bromide, gallium phosphide, indium phosphide, calcium fluoride, zinc telluride, bismuth germanium oxide and aluminum nitride. In addition, a variety of specimens have been submitted for specific studies such as phase identification, crystallinity and chemical analysis.

DD FORM 1 NOV 68 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Electronic Materials Optical Materials Thin Films Structural Characterization Physical Properties X-Ray Diffraction Electron Diffraction						

AFCRL-TR-73-0070

PHYSICAL CHARACTERIZATION OF ELECTRONIC MATERIALS, DEVICES AND THIN FILMS

by

S. Andrew Kulin
Konstantin Kreder

ManLabs, Inc.
21 Erie Street
Cambridge, Massachusetts 02139

CONTRACT NO. F19628-70-C-0140

Project No. 5620
Task No. 562003
Work Unit No. 56200301

Final Report

1 December 1969 - 30 November 1972

1 December 1972

Contract Monitor: Norman E. Pickering
Solid State Sciences Laboratory

Prepared for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS 01730

FOREWORD

This report was prepared by ManLabs, Inc., 21 Erie Street, Cambridge, Massachusetts, under Air Force Contract No. F19628-70-C-0140. The work was administered by the Office of Aerospace Research, Air Force Cambridge Research Laboratories, United States Air Force, Bedford, Massachusetts, with Mr. Norman Pickering providing technical liason.

ManLabs personnel that have participated in this program are Dr. S. Andrew Kulin, Dr. Edward V. Clougherty, Harvey Nesor, Dr. Edward P. Warekois, Konstantin Kreder, Joseph Davis, Kathleen Meaney and Harry Tushman.

This is a technical report and describes studies which were initiated 1 December 1971 and were concluded 30 November 1972.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

A continuing investigation of the formation and characterization of high purity crystalline materials is being carried out by the Properties and Phenomena Branch, Solid State Sciences Laboratory, Air Force Cambridge Research Laboratory. In general, studies have been concerned with preparing materials which have desirable electronic and/or optical properties, and with developing and evaluating methods of crystal preparation. ManLabs, Inc. has conducted a service effort directed toward the characterization of selected chemical, physical and structural properties of specimen materials submitted by workers at AFCRL; in addition, ManLabs, Inc. has provided specific services such as crystal orientation, cutting and surface preparation. The various experimental methods which are employed have been described in "Physical Characterization of Electronic Materials, Devices and Thin Films," by Dr. S. Andrew Kulin, et. al., Final Report, AFCRL-67-0173, November 30, 1969.

A wide variety of specimens have been submitted for characterization; the results of ensuing analyses have been reported individually for each specimen (or group of specimens) in the form of a letter report. Sections of this report describe some of the experimental methods and procedures that have been employed and summarize the results of the analytical services. The presentation of experimental results is subdivided into sections concerned with the methods of analysis employed.

II. EXPERIMENTAL METHODS

The following experimental methods and procedures have been employed in the course of the program.

A. X-Ray Diffraction

Powder sample identification and lattice parameter measurements have been carried out by X-ray diffraction methods. When large samples are available, one utilizes a diffractometer which yields a strip chart recording of peak intensity versus Bragg angle. Small quantities of material are examined by the Debye-Scherrer camera technique. The specimen is placed in a small diameter capillary tube, which is positioned at the center of the camera. Diffraction lines are recorded on a film located on the circumference of the camera. In either case, measurements of the diffraction line positions allow calculation of the interplanar spacings of the lines and identification of the specimen material.

Back reflection X-ray patterns have been utilized to determine the crystallinity of specimens. Polycrystalline materials yield ring (pinhole) patterns which can be used for qualitative measures of grain size, lattice parameter and preferred orientation. Single crystal materials yield spot (Laue) patterns which are utilized to confirm crystallinity, to provide crystal orientation and to give a qualitative estimate of crystal strain and perfection. The lattice perfection is based upon observed spot distortion, diffuseness or fragmentation. Single crystal orientation is carried out by conventional back reflection Laue methods. The specimen holder is transferred from the X-ray unit directly to the grinding machine where specific specimen configurations are prepared by appropriate cutting and grinding. When required, the specimen faces are polished by hand lapping with diamond, alumina or other special abrasive materials.

B. Crystal Cutting and Polishing

The experimental procedures used to fabricate crystals of various sizes and shapes were generally as follows: the boule was mounted onto a brass block with "quartz cement" and was X-ray oriented to the specific crystallographic plane. The required shapes were then cut and ground with diamond wheels using a Sanford Surface Grinder and machine polished or lapped using a Crane Lapmaster 12. After rough polishing, the final orientation of the crystal was checked by taking an X-ray Laue pattern and in certain cases by use of a horizontal diffractometer.

In order to obtain crystals of good quality, i.e. smooth surface and completely without flaws, the machine lapping operation

was followed by hand lapping on a precision ground glass covered with suitable abrasive and moving with a sweeping motion over the glass surface preferably in the form of figure eights. Surface flatness of about one wavelength of sodium light and surface parallelism of about ten seconds of arc or better was routinely maintained during the fabrication of the crystallographically oriented plates of quartz, linobates, germanates and other crystals.

C. Hardness

Specimens were mounted in epoxy and were polished to about a one micron surface finish to provide a uniform flat surface. Hardness measurements were made on a Leitz Durimet Microhardness Tester utilizing either Knoop or Vickers pyramid indentors. Hardness values are reported in kg/mm^2.

D. Determination of Strength Properties of Various Alkali Halide Crystals

Transverse bend strength properties of the alkali halide crystals were determined by subjecting specimens of rectangular cross section to four-point bending. Four-point bending was chosen because the "pure bending" in this test eliminated the additional shear stresses encountered in three-point bend testing. The test results yielded values of the modulus of rupture for each of the three alkali halide materials.

A special four-point bending fixture was designed and constructed for these tests. Limitations on specimen size were dictated by the size of the single crystal boules available. The outer span was made about 1.20 inch in length (overall specimen length at least 1.4 inch) and the inner span length was made equal to 0.60 inch. In order to insure axiality during application of load, spherical ball joint (rod ends) connections were attached to the bend test fixture.

Loads were measured and recorded by means of a newly designed 50-pound capacity beam type load cell (2M.V./volt) manufactured by BLH Electronics, Inc. Using a BLH model 3546 variable voltage transducer power supply, it was possible to measure loads to well within 0.01 pound from the bridge circuit output. The bending load was recorded on a fast response Minneapolis-Honeywell recorder.

Specimen loading was accomplished using a ManLabs, Inc. constant strain rate Polyani-type tensile tester. In these tests a specimen deflection rate of approximately 1.5×10^{-4} inch per

second was employed. The modulus of rupture was calculated from the maximum load applied, the dimensions of the four-point bending spans and from the specimen dimensions. The maximum tensile or fiber stress is given by:

$$\sigma_{max} = \frac{Pa}{2Z} \qquad (1)$$

where P is the applied four-point (total) bending load, a is the moment arm (in this case $a = \ell/4$, where ℓ is the outer span length), and Z is the section modulus. In the case of a rectangular cross section, $Z = bh^2/6$, where b is the specimen width and h is the specimen height. Equation 1 for the modulus of rupture, σ_{max}, reduces to:

$$\sigma_{max} = \frac{3P\ell}{4bh^2} \qquad (2)$$

E. Fabrication of Modified Cylinders

During this reporting period work has progressed on the fabrication of modified cylinders out of $LiNbO_3$ and BGO. Techniques have been applied which permitted highly precise grinding of the cylinder outer diameters, i.e. T.I.R. of only a few millionths of an inch. Special devices have been designed and constructed to polish the outer diameters on a centerless principle. Excellent polished surface finishes have been obtained.

The fabrication of these modified cylinders necessitated the construction of X-ray orientation devices. The polished cylinders were protected with a plastic coating during X-ray orientation, grinding and polishing of the flat surfaces. Attention was given to methods of handling during microscopic inspection and ultimately during delivery of these precise parts. This part of the program is completed.

III. EXPERIMENTAL RESULTS

A listing of the various analytical services provided during the period from December 1971 to December 1972 is presented in Table 1. The experimental findings are summarized below.

A. X-Ray Diffraction

Seven powder samples, identified as Nos. 8:18:1,2,3,4,5, 6 and 7 were submitted for X-ray diffraction analysis. Diffraction scans were obtained for each specimen employing nickel filtered copper radiation, covering the range $2\theta = 10$ to $80°$. The diffraction data were compared with NBS and ASTM standard data for SiC, Si_3N_4, SiO_2, Si, C, CaO and $CaSi_2$ and other potential phases. The results are summarized below:

AFCRL No.	Specimen No.	Chemistry
03497	8:18:1	α-SiC, $CaSi_2$
	8:18:2	Si, $CaSi_2$
	8:18:3	$CaSiN_2$
	8:18:4	
	8:18:5	α-SiC, $CaSi_2$, Si
	8:18:6	α-SiC, Si, $CaSi_2$
	8:18:7	α-SiC, Si

B. Crystal Cutting and Polishing

A number of quartz, potassium chloride, sodium chloride, potassium bromide, gallium phosphide, bismuth germanate, lithium niobate, zinc telluride and calcium fluoride crystals have been X-ray oriented, cut and polished according to stated size specifications and specimen orientations. The crystals were mounted onto steel blocks with "quartz cement" and were oriented to the specified crystal plane by back reflection X-ray Laue methods. The required pieces were fabricated by cutting and grinding with diamond wheels and were then polished to obtain the desired surface finish. The final orientations were checked by X-ray Laue patterns and, in certain cases, by use of a horizontal diffractometer designed for single crystal orientation work.

A number of service requests during this reporting period required crystals to be polished having surface finishes at least $\lambda/10$ in flatness.

The various crystals, crystallographic orientations and specimen dimensions are given in Tables 2 and 3.

C. Microhardness Measurements

Microhardness measurements were performed utilizing a Leitz Microhardness Tester with a Knoop indentor and a 15 gram load. An average hardness value based on five readings was obtained for various salt crystals and the results are summarized in Table 4.

D. Strength Properties of Alkali Halide Crystals

The as-received single crystal boules were approximately 1/2 inch diameter by about 1 1/2 inch in length. The materials were Czochralski grown with the boule axes in the <100> direction. The KCl and KBr boules were fabricated into rectangular bar specimens of 0.20 inch by 0.30 inch by about 1.4 inch in length. The boules were cut on a string saw and the bars were finish ground by hand lapping using 600 grit. Care was taken to insure that any final minute surface scratches were parallel to the long axis of the specimen faces.

Since residual stresses of considerable magnitude were present in the as-grown KCl·KBr boules, this material was given a stress relieving cycle at ManLabs. It was slowly heated to 650°C, held at temperature for four hours and then furnace cooled to ambient temperature. In order to insure success in fabrication the KCl·KBr bend specimens were fabricated by hand lapping only on all sides with cutting operations omitted.

The modulus of rupture values obtained on the KCl, KBr and KCl·KBr boules are given in Table 5.

TABLE 1

LIST OF SERVICES

Index	AFCRL No.	Requestor	Specimen Nos.	Material	Analytical Methods**
5-30*	04077	Slobodnik	S-A1	BeO	XRL, CC
5-33	04076	Slobodnik		$LiNbO_3$	XRL, CC, F
5-37	04082	Slobodnik		Quartz	XRL, CC, F
5-116	04352	Slobodnik	6-A	$LiNbO_3$	CC
9-1	03060	Posen	LQ-109	KCl·KBr	Sintering
9-2	03024	Bruce	LQ-98	NaCl·KCl	H
			LQ-99	NaCl·KCl	H
			LQ-109	KBr·KCl	H
9-3	04353	Slobodnik		Aluminum	F
9-4	04354	Carr	DL-A4	$LiNbO_3$	F, CC
9-5	04375	Slobodnik	5-21-72	$LiNbO_3$	CC
			1-13-72	$LiNbO_3$	CC
9-6	03092	Capone	AF-52-AL-0102	Si	XRL
			AF-19-P010L	Si	XRL
9-7	04355	Carr	5-20-1-69	$LiNbO_3$	CC
9-8	05363	Hunt		GaP	CC
9-9	05364	Hunt		GaP	CC

*Work in Progress.

**XRL--X-ray Laue; XRD--X-ray diffraction analysis; CC--crystal cutting and/or grinding, polishing; CA--chemical analysis; H--hardness; ES--emission spectroscopy; EPM--electron probe microanalysis; D--density; TE--thermal expansion; F--Fabrication; ED--electron diffraction.

TABLE 1 (Continued)

LIST OF SERVICES

Index	AFCRL No.	Requestor	Specimen Nos.	Material	Analytical Methods**
9-10	03061	Bruce	LQ-113	GaP	XRL, CC
9-11	03062	Bruce	LQ-111	GaP	XRL, CC
9-12	05363	Hunt		InP	CC
9-13	04356	Carr	3-15-70	$LiNbO_3$	CC
9-14	03064	Bruce	LQ-113	KCl·KBr	H
			LQ-114	KCl·NaCl	H
9-15	03093	Buckmelter	GaP-1	GaP	CC
9-16	03065	Bruce	LQ-115	KCl·KBr	H
			LQ-117	KCl	H
9-17	03111	Buckmelter		ZnTe	CC
10-1	04357	Carr	3-15-70	$LiNbO_3$	CC
10-2	04358	Slobodnik	6-B	$LiNbO_3$	XRL, CC
10-3	03068	Bruce	LQ-128	KCl·KBr	CC, H
10-4	03112	Clark		KCl	CC
10-5	03069	Bruce	LQ-131 to LQ-148	KCl·KBr KCl, NaCl	CC, H
10-6	03115	Pickering	LQ-155	KCl·KBr	F, CC

*Work in progress.

**XRL--X-ray Laue; XRD--X-ray diffraction analysis; CC--crystal cutting and/or grinding, polishing; CA--chemical analysis; H--hardness; ES--emission spectroscopy; EPM--electron probe microanalysis; D--density; TE--thermal expansion; F--fabrication; ED--electron diffraction.

TABLE 1 (Continued)

LIST OF SERVICES

Index	AFCRL No.	Requestor	Specimen Nos.	Material	Analytical Methods**
10-7	03117	Posen	LQ-151	KCl	Bend Test
			LQ-152	KBr	Bend Test
			LQ-153	KCl-KBr	Bend Test
	03120	Posen	LQ-161	KCl-KBr	Bend Test
10-8	03118	Posen	LQ-157	KCl	F
			LQ-158	KBr	F
			LQ-159	KBr-KCl	F
10-9	04359	Slobodnik	1-31-72T	BGO	CC
10-10	03119	Pickering	LQ-160	KCl-KBr	F, CC
10-11	04360	Slobodnik	6-A	$LiNbO_3$	CC
10-12	04361	Carr	YZ-cut	$LiNbO_3$	CC
			ST-cut	Quartz	CC
10-13	04347	Brunn	2-72	Quartz	XRL, CC
10-14	03073	Lipson	LQ-90	KCl	F, CC
			LQ-106	KCl	F, CC
			LQ-88	KCl-KBr	F, CC
			LQ-91	KCl-KOH	F, CC
			LQ-102	KCl	F, CC

** XRL--X-ray Laue; XRD--X-ray diffraction analysis; CC--crystal cutting and/or grinding, polishing; CA--chemical analysis; H--hardness; ES--emission spectroscopy; EPM--electron probe microanalysis; D--density; TE--thermal expansion; F--fabrication; ED--electron diffraction.

TABLE 1 (Continued)

LIST OF SERVICES

Index	AFCRL No.	Requestor	Specimen Nos.	Material	Analytical Methods**
			LQ-70	KBr	F, CC
			LQ-99	KCl·NaCl	F, CC
			LQ-104	KCl·CaCl	F, CC
10-15	04363	Slobodnik	3-15-71	$LiNbO_3$	CC
10-16	04364	Slobodnik		BGO	XRL
10-17	03124	Armington	4:26:1-76	GaP	CC
10-18	04306	Klausutis	LQ-180	InP	CC
10-19	03133	Buckmelter		InP	CC
10-20	04297	Klausutis	LQ-181	InP	XRL, CC
10-21	03074	Lipson	LQ-97	KBr·KCl	F, CC
11-1	02477	Hilton	5:25:1-72	GaP	XRL, CC
11-2	04439	Bruce	LQ-184	KCl	CC
			LQ-185	KCl	CC
			LQ-186	KCl·KBr	H, CC
11-3	04299	Klausutis	LQ-191	InP	CC
11-4	04365	Slobodnik		BGO	XRL, CC
11-5	04435	Lipson	LQ-100	KCl·CaCl	CC

** XRL--X-ray Laue; XRD--X-ray diffraction analysis; CC--crystal cutting and/or grinding, polishing; CA--chemical analysis; H--hardness; ES--emission spectroscopy; EPM--electron probe microanalysis; D--density; TE--thermal expansion; F--fabrication; ED--electron diffraction.

TABLE 1 (Continued)

LIST OF SERVICES

Index	AFCRL No.	Requestor	Specimen Nos.	Material	Analytical Methods**
			LQ-204	KCl	CC
			LQ-205	KCl	CC
11-6	03102	Klausutis	LQ-208	InP	XRL, CC
11-7	04367	Slobodnik		BGO	XRL, CC
11-8	04368	Slobodnik	6-26-72	BGO	XRD, CC
11-9	04369	Slobodnik	5-26-72	BGO	CC
11-10	04157	Dugger	6:26:1-72	$SiO_2 \cdot C$	XRD
			5:26:2-72	$Al_4C_3 \cdot Al(NO_3)_2$	XRD
			6:26:3-72	$AlN \cdot C$	XRD
			6:27:4-72	$AlN \cdot Al(NO_3)_3C$	XRD
			6:27:1-72	$Ca(OH)_2$	XRD
11-11	04371	Carr	YZ-cut	$LiTaO_3$	CC
11-12	03311	Larkin	LQ-211	GaP	CC
			LQ-212	GaP	CC
			LQ-213	GaP	CC
11-13	03494	Klausutis	LQ-214	InP	CC
11-14	04372	Slobodnik	4-1-71	BGO	CC

** XRL--X-ray Laue; XRD--X-ray diffraction analysis; CC--crystal cutting and/or grinding, polishing; CA--chemical analysis; H--hardness; ES--emission spectroscopy; EPM--electron probe microanalysis; D--density; TE--thermal expansion; F--fabrication; ED--electron diffraction.

TABLE 1 (Continued)

LIST OF SERVICES

Index	AFCRL No.	Requestor	Specimen Nos.	Material	Analytical Methods**
11-15	04373	Slobodnik	9-21-70	$LiNbO_3$	CC
			2-5-71	$LiNbO_3$	CC
11-16	04366	Slobodnik		BGO	XRL, CC
11-17	04374	Slobodnik		BGO	XRL, CC
11-18	03326	Pickering	LiF-1	LiF	CC
			LiF-2	LiF	CC
11-19	03350	Slobodnik	4-30-71T	BGO	CC
11-20	03351	Slobodnik	8-10-72	BGO	CC
11-21	03352	Slobodnik	8-14-72	BGO	CC
11-22	03353	Slobodnik		BGO	CC
11-23	03280	Hilton	7:20:1-72	GaP	CC
11-24	03314	Hilton	7:20:1-72	GaP	CC
12-1	03497	Dugger	8:18:1-1,2,3,4, 5,6 & 7	SiC	XRD
				Si_3N_4	XRD
				SiO_2	XRD
				Si	XRD
				C	XRD
				CaO	XRD
				$CaSi_2$	XRD

** XRL--X-ray Laue; XRD--X-ray diffraction analysis; CC--crystal cutting and/or grinding, polishing; CA--chemical analysis; H--hardness; ES--emission spectroscopy; EPM--electron probe microanalysis; D--density; TE--thermal expansion; F--fabrication; ED--electron diffraction.

TABLE 1 (Continued)

LIST OF SERVICES

Index	AFCRL No.	Requestor	Specimen Nos.	Material	Analytical Methods**
12-2	03354	Slobodnik	4:1:71	BGO	CC
12-3	03250	Bruce	#100,110 & 111	KCl·KBr	XRL, CC
12-4	03495	Klausutis	B13P2-EP	$B_{13}P_2$	CC
12-5	05450	Hunt	21,26,269,270 274 and 277	ZnSe	CC
12-6	03355	Slobodnik	X and Y	$LiNbO_3$	CC
12-7	03327	Clark	NaCl	NaCl	CC
12-8	03356	Slobodnik	6-26-72	BGO	CC
12-9	03252	Bruce	LQ-154	KCl	XRL, CC
12-10	03281	Hilton	9:18:1-72	GaP	CC
12-11	03357	Slobodnik	1-31-72T 8-10-72	BGO	CC
12-12	03358	Budreau	ST	Quartz	CC
12-13	00618	Posen		KCl	CC
12-14	03359	Slobodnik	6-26-72	BGO	CC
12-15	02482	Hilton		Quartz	CC
12-16	03329	Posen	6: diam disc	KCl	F, CC
12-17		Slobodnik	Mod. Plates	BGO	F, CC

** XRL--X-ray Laue, XRD--X-ray diffraction analysis; CC--crystal cutting and/or grinding, polishing; CA--chemical analysis; H--hardness; ES--emission spectroscopy; EPM--electron probe microanalysis; D--density; TE--thermal expansion; F--fabrication; ED--electron diffraction.

TABLE 1 (Continued)

LIST OF SERVICES

Index	AFCRL No.	Requestor	Specimen Nos.	Material	Analytical Methods**
12-18	03346	Lipson	LQ-87A	KCl	F, CC
			LQ-90		F, CC
12-19	03347	Lipson	LQ-205	KCl	F, CC
12-20	03349	Lipson	X-105	KCl	F, CC

** XRL--X-ray Laue; XRD--X-ray diffraction analysis; CC--crystal cutting and/or grinding, polishing; CA--chemical analysis; H--hardness; ES--emission spectroscopy; EPM--electron probe microanalysis; D--density; TE--thermal expansion; F--fabrication; ED--electron diffraction.

TABLE 2

CRYSTAL ORIENTATION

Job.No.	Specimen No.	Description	Orientation, hkl
04077	S-A1	BeO	$(10\bar{1}0),(2\bar{1}\bar{1}0),(0001)$
04076	Mod. Cylinder	$LiNbO_3$	$(2\bar{1}\bar{1}0),(10\bar{1}0)$
04082	Mod. Cylinder	Quartz	Normal; 30° from $(10\bar{1}0)$, $(2\bar{1}\bar{1}0)$
03092	AF-52-A10102	Si	(100)
	AF-19-P010L	Si	(100)
03061	LQ-113	GaP	(111)
03062	LQ-111	GaP	(111)
04077	S-A1	BeO	$(10\bar{1}0),(2\bar{1}\bar{1}0),(0001)$
04358	6-B	$LiNbO_3$	Normal; 37.5° from $(0001),(10\bar{1}0)$
04347	2-72	Quartz	$(10\bar{1}0),(2\bar{1}\bar{1}0),(0001)$
04364		BGO	(100),(110)
04297	LQ-181	InP	Polycrystal
02477	5:25:1-72	GaP	(111)
04365	6" Long Boule	BGO	(110)
03102	LQ-208	InP	Crystallinity Check
04367	Mod. Cylinder	BGO	(001),(110)
04368	6-26-72	BGO	40°9' from (100) in (100)·(110) plane
04371		$LiTaO_3$	YZ-cut
04366	Mod. Cylinders	BGO	(001),(110)
04374	10" Long Boule	BGO	(001),(110)
03250		KCl·KBr	(100),(110),(111) & (112)
03252	LQ-154	KCl	(100),(110) & (111)

TABLE 3

CRYSTAL CUTTING AND SPECIMEN GEOMETRIES

Ser. Reg. No.	Material	Description
04076	$LiNbO_3$	0.600" diam. x 2.0" long cylinder (two units)
04082	Quartz	0.600" diam. x 2.0" long cylinder
05363	GaP	0.125" x 0.125" x 0.375" rod
		0.125" x 0.125" x 0.500" rods (two)
05364	GaP	0.125" x 0.125" x 0.625" rod
		0.125" x 0.125" x 0.500" rods (two)
03061	GaP	0.187" x 0.187" x 1.000" rods (four)
03062	GaP	0.500" diam. x 0.040" thick discs (seventeen units)
05365	InP	0.060" thick slices (two units)
03112	KCl	1/2" diam. x 1/8" thick slice
		1/2" diam. x 3/16" thick slice
03115	KCl·KBr	1.79 cm. diam. x 1.0 cm. long cylinder
03119	KCl·KBr	1.79 cm. diam. x 1.0 cm. long cylinder
04347	Quartz	0.575" x 0.350" x 0.120" plate
03073	KCl·KBr	1 cm. x 1 cm. x 1 cm. cubes (three)
	KCl	1 cm. x 1 cm. flats (two)
	KCl·CaCl	1.2 cm. x 1.2 cm. x 1.0 cm. bar (one)
03124	GaP	3/16" x 3/16" x 7/8" seeds (six)
02477	GaP	3/16" x 3/16" x 1 3/4" seeds (two)
04439	KCl	1 cm. x 1 cm. x 1 cm. (two)
	KCl·KBr	1 cm. x 1 cm. x 1 cm. (one)
04299	InP	Random Cut (one)
04365	BGO	7 mm. x 4 mm. x 152 mm. (two)
04435	KCl	1 cm. cube (two)
	KCl·CaCl	1 cm. cube (one)
03102	InP	Random Cut (one)
04367	BGO	25 mm diam. x 50 mm. long cylinder (one)

TABLE 3 (Continued)

CRYSTAL CUTTING AND SPECIMEN GEOMETRIES

Ser. Reg. No.	Material	Description
04371	$LiTaO_3$	25.4 mm. x 9 mm. x 1.02 mm. plate (one)
		25.4 mm. x 9 mm. x 0.51 mm. plate (one)
03494	InP	Longitudinal Cut (one)
04366	BGO	25 mm. diam. x 50 mm. long cylinder (one)
04374	BGO	7 mm. x 4 mm. x 152.4 mm plate (two)
03326	LiF	1.79 cm. diam. x 0.6 cm. thick disc (two)
03280	GaP	3/16" x 3/16" x 1 1/8" seed (one)
03314	GaP	3/16" wide x about 1" long seed (one)
03354	BGO	25.4 mm. x 9 mm. x 4 mm. plate (one)
03250	KCl·KBr	1/4" thick slices (three)
03355	$LiNbO_3$	35.4 mm. x 9 mm. x 4 mm. plate (one)
03252	KCl	1/2" x 1/2" x 1/4" slices (three)
03281	GaP	1/4" slice (one)
02482	Quartz	60 mm. diam. tubes (two)
03329	KCl	6" diam. window (one)
03345	KCl & KBr	0.2 mm. and 0.4 mm. thick slices (four)
03346	KCl	0.4 mm. thick slices (two)
03349	KCl	0.2 mm. thick slice (one)

TABLE 4

MICROHARDNESS MEASUREMENTS

Job No.	Spec. No.	Material	KHN
03024	LQ-98	NaCl·KCl	55.7
	LQ-99	NaCl·KCl	57.9
	LQ-109	KBr·KCl	21.0
03064	LQ-113	KCP·KBr	24.0
	LQ-114	KCP·NaCl	23.8
03065	LQ-115	KCl·KBr	21.4
	LQ-117	KCl	18.1
03068	LQ-128	KCl·KBr	32.05
03069	LQ-131	NaCl·KCl	25.16
	LQ-132	NaCl·KCl	24.0
	LQ-133	NaCl·KCl	27.87
	LQ-134	NaCl·KCl	24.89
	LQ-135		25.10
	LQ-136		24.37
	LQ-137		25.37
	LQ-138	NaCl·KCl	31.06
	LQ-139	NaCl·KCl	24.94
	LQ-140	NaCl·KCl	28.92
	LQ-141		31.50
	LQ-142		29.54
	LQ-143		31.36
	LQ-144		37.15
	LQ-145		84.70
	LQ-146		44.83
	LQ-147		54.63
	LQ-148		54.63
04439	LQ-184	KCl	9.31
	LQ-185	KCl	8.77
	LQ-186	KCl·KBr	19.20

TABLE 5

MODULUS OF RUPTURE DATA

Material	Identification No.	Modulus of Rupture, psi
KCl	LQ-151	680
KBr	LQ-152	850
KCl·KBr	LQ-161	1350